A SOFTWARE DEFINED EARTH OBSERVATION MISSION PARADIGM

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ABSTRACT

New Space trend has been characterized by a disruptive approach, in which actors have tried to make the most out of traditional methods and processes while applying a fast delivery and low cost perspective. The trend has been benefiting from many factors, with technological miniaturization and innovation being among the most important.
As a global player of NewSpace, SATLANTIS develops solutions for Earth Observation (EO) which combine innovations from astrophysics and space engineering and offers products and services with an original business approach, not limited to a supplier and subsystem provision scheme.
In this work, the company aims at presenting its Full Solution paradigm, a model enabled by specific features of its core technology, and by partnerships throughout the value chain. The Full Solution paradigm is based upon software defined EO mission theory, with key elements like: Agile Observation Modes; Smart Image Pre-processing, enabled by the Ultra High-Resolution (UHR) algorithm; high resolution Video generation. All of this to provide innovative Analysis-Ready Data (ARD) products delivered through an infrastructure for end-to-end mission data management. Such features, and the search for more capabilities like Stereo imaging, ultimately aim at impacting the end-to-end mission data management and exploitation of products coming from EO missions.

1 INTRODUCTION

Space activities went from being Government-driven endeavours to being commercially available assets and even commodities, with a huge push from miniaturisation of technology that enabled a democratisation of Space. Up to just a few decades ago, satellites used to weight tonnes and being part of huge efforts in terms of financial resources, given the expensive and really long development times. Small Satellites (loosely defined as satellites weighing <500 kg) changed the paradigm, by reducing time and costs and making Space missions accessible and financially viable for private companies and even universities (e.g., CubeSat missions).
Small Satellites, and generally the so-called NewSpace philosophy, have become a focal point of interest for users worldwide, thanks to their low cost and fast delivery development and launch, which make them affordable assets for various applications. Also, the technological miniaturization trend has been enabling Small Satellites to board advanced instruments, and to offer high-end specifications and performances, which is also contributing to their success among users. The possibility to deploy multiple satellites, with an even smaller cost than one single traditional commercial satellite, is allowing users and constellations operators to offer high revisit, high volume of data, and payload diversification to perform data fusion [1].
It is then not a surprise that even Governmental entities are now looking at Small Satellites as a resource, complementary to existing assets. The Small Satellites missions cannot replace traditional assets but, for their characteristics of responsiveness and agile development and deployment in orbit, can play a crucial role in increasing the spatial and temporal resolutions available to users worldwide.

An example of such complementarity is represented by the Copernicus Contributing Missions (CCM) initiative, promoted by the European Commission and implemented by the European Space Agency, that consists in selecting specific commercial missions able to complement the output of the Copernicus Sentinel missions. These CCMs are developed by ESA, its Member States and other European and international third party operators, and help cover the needs of Copernicus Service Providers, particularly for very high resolution data [2].
As a global player of New Space, Satlantis develops solutions for Earth Observation (EO) which combine innovations from astrophysics and space engineering and offers products and services with an original business approach, not limited to a supplier and subsystem provision scheme, but aiming at covering the entire value chain, via key partnerships with other companies, to provide customers with turnkey solutions for specific problems on Earth.

2 EARTH OBSERVATION MISSIONS

SATLANTIS was able to demonstrate in orbit its technology in 2020, and since then the company has been developing, launching, and operating a total of six missions, which are listed below.

iSIM-170 IOD
The first mission launched by SATLANTIS consisted of an In-Orbit Demonstration (IOD) of the iSIM-170 payload (see Figure 2-1) that, after passing all NASA and JAXA reviews and requirements, was launched the 20th of May 2020 and installed on the i-SEEP platform outside of the Japanese KIBO module of the International Space Station (ISS) the 11th of June 2020 for its first mission. This three month mission allowed SATLANTIS to demonstrate in orbit the Ultra-High Resolution (UHR) algorithm and the submetric resolution of iSIM-170, thanks to the acquisition of more than 64.000 images [3].

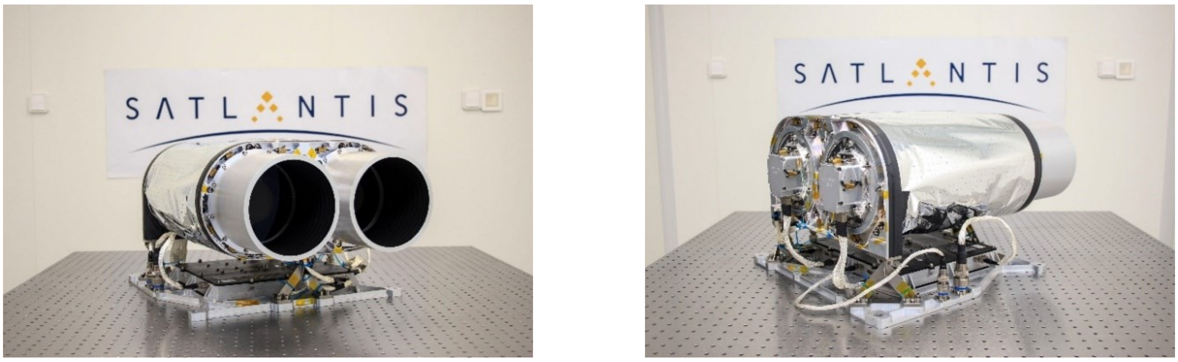

Figure 2-1: iSIM-170 FM after final assembly.

CASPR – DoD STP-H7 programme
In 2021, SATLANTIS demonstrated in orbit its second payload, i.e., iSIM-90 (see Figure 2-2), via CASPR, a technology demonstration mission of the USA's Department of Defence (DoD), within the Space Technology Program Houston 7 (STP-H7). SATLANTIS participates in collaboration with SHREC. SHREC is the Centre for Space, High-Performance, and Resilient Computing at the National Science Foundation (USA). iSIM-90 was installed onboard an external pallet at the International Space Station (ISS) on December 21st, 2021, and is currently under nominal operations. During the mission, the optomechanics, detectors unit and multispectral filters haves been demonstrated, together with the multispectrality and agility feature of the technology [4].

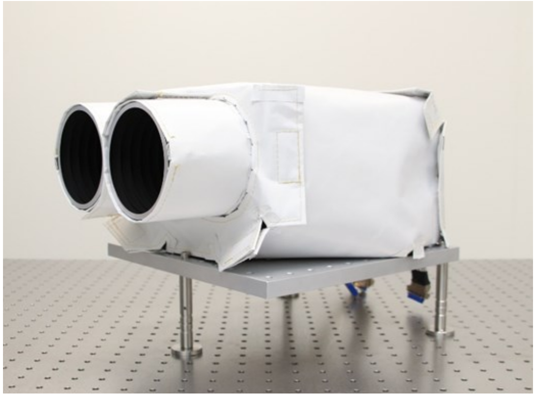

Figure 2-2: iSIM-90 Flight Model for CASPR Mission.

URDANETA-ARMSAT_1 Mission

In 2022, SATLANTIS launched its first Eart Observation (EO) full satellite mission, with iSIM-90 onboard a 16U CubeSat sensor-bus. The satellite was purchased by Geocosmos, the Armenian company subsidiary of the RA Ministry of High-Tech Industry. Urdaneta-ARMSAT_1 (see Figure 2-3) was launched on May 25th, 2022, from Cape Canaveral Space Force Station, onboard a SpaceX Falcon 9 rocket with the Transporter 5 mission and released at 530 km altitude. ARMSAT_1 satellite's disruptive capabilities include Ultra-High Resolution (UHR) of 2 m, multispectral capacity (RGB and NIR, 4 bands), agility (>1 deg/s slew manoeuvres) and low mass (16.4 kg). These features drive and impact several Earth observation's added value applications, enhancing the capabilities of satellite data end-users.

Figure 2-3: Urdaneta-ARMSAT_1 Flight Model.

GEISAT Precursor Mission

The second SATLANTIS complete mission designed, operated and managed by the company itself was GEISAT Precursor (see Figure 2-4). The main end-use application for which it was designed is the location, detection, and quantification of methane gas emissions for companies in the Oil and Gas sector. The mission is based on iSIM technology, which allows simultaneous imaging in the visible and short wave infrared spectra. The mission was successfully launched on June 12th June 2023 from Vandenberg Space Force Base in California, with the Transporter-8 mission onboard a SpaceX Falcon 9 rocket. This Precursor Mission represents the first SATLANTIS end-to-end solution for methane emissions detection and quantification. It will be followed by a Constellation of satellites dedicated to measuring CH_4 and other greenhouse gases. [5] This mission has been awarded as Copernicus Contributing Mission for Atmosphere services.

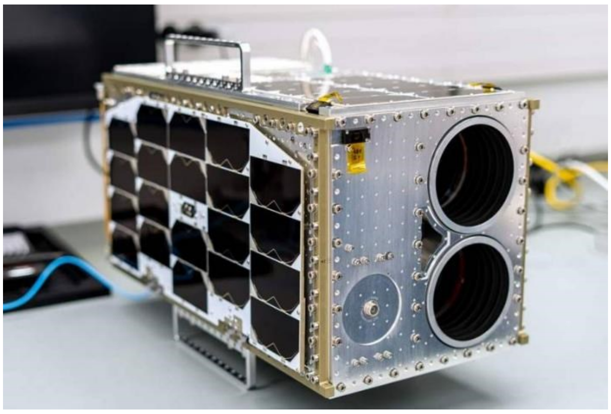

Figure 2-4: GEISAT Precursor Flight Model.

MANTIS Mission
MANTIS is a commercial mission funded under the European Space Agency´s (ESA) InCubed program where SATLANTIS acts as the key supplier of the iSIM-90 optical payload (see Figure 2-5), embarked on a ~20kg EO CubeSat mission capable of providing multispectral high-resolution images for Oil & Gas applications. The satellite was launched on November 11th, 2023, onboard the SpaceX's Transporter-9 mission that lifted off from California's Vandenberg Space Force Base [6].

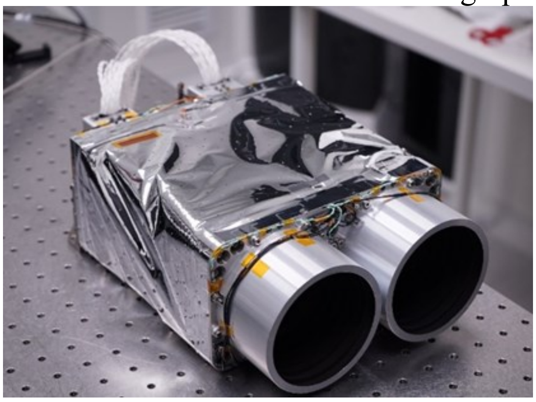

Figure 2-5: Flight Model of the MANTIS' iSIM instrument.

HORACIO Mission
On March 4th, 2024, the third full satellite developed by SATLANTIS, called HORACIO (see Figure 2-6), was launched from the Space Launch Complex at Vandenberg Space Force Base in California, with the Transporter-10 mission onboard a SpaceX Falcon 9 rocket, a rideshare of satellites to a Sun Synchronous Orbit.
HORACIO is a complete mission similar to the GEISAT mission, consisting of a 16U CubeSat satellite with an integrated iSIM-90 camera offering simultaneous VNIR and SWIR coverage, with resolution of 2 m in VNIR, and 4 m in SWIR.
The mission is targeting multiple EO applications - ranging from infrastructure monitoring, methane gas emissions quantification, coastal and border awareness, among others.

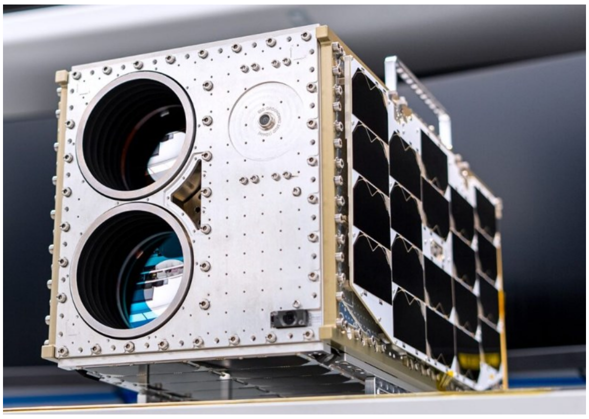

Figure 2-6: HORACIO Flight Model.

Besides the missions already launched, SATLANTIS has a short- and medium-term strategy that consists of planning and executing a roadmap for the coming years around full satellite missions directly operated by or for end customers.
Between 2024 and 2025, SATLANTIS will launch the GARAI Mission, consisting of two Microsatellites embarking two payloads each one, i.e., one iSIM-90 and one iSIM-170, with different spectral coverage. The combination of spatial and spectral resolutions of the four payloads will enable a variety of applications including security (maritime and borders surveillance), energy (monitoring of plants and pipelines), environment (detection of methane emissions), among others.

3 THE FULL SOLUTION PARADIGM

Most of the missions presented above are examples of what SATLANTIS defines as Full Solutions, a model in which the company is not acting merely as optical payload provider but is able to provide customers with turnkey EO missions, via strategic partnerships with companies covering key elements in the full value chain.

3.1 iSIM Technology

This paradigm revolves around the integrated Standard Imager for Microsatellites (iSIM) technology, corresponding to a family of high- and very high-resolution multispectral imagers designed and manufactured by SATLANTIS, that can be adapted to different users' requirements to address applications in various sectors.
From a technological standpoint, the iSIM cameras have a binocular configuration with a diffraction-limited optical system over the entire field-of-view. iSIM is a Push-Frames Technology that enables three major benefits out of the instruments acquisition strategy, namely, (1) the high rate of acquisition (>26 frames per second (FPS)) allows the application of the Ultra-High Resolution (UHR) algorithm developed by SATLANTIS to improve the quality of raw frames; (2) the agile acquisition mode to acquire images as the satellite observes along and across track; (3) the multispectrality without degradation of spatial resolution enabled thanks to the filters distribution in front of the detector and over the channels.
The UHR is an algorithm that corrects, fuses, mosaics, and deconvolves mono-band frames and co-registers information from different spectral bands to generate a multiband bundle data product [7]. The iSIM push frame technology produces bi-dimensional field of views that, combined with a high frame rate and short exposure times ensures no blurring while the satellite manoeuvres during acquisitions and a sequence of single frames with a common overlap area that can be combined to create higher signal-to-noise, resolution or contrast final data products.

The UHR is configured to process data generated while the satellite manoeuvres during acquisition. This feature leverages the iSIM agile acquisition mode, offering a wide range of manoeuvrability and data product configurations, such as:

- Non Linear Tracking mode, to observe irregular earth profiles such as coastlines, borders or user infrastructures.
- Back-Scanning mode, to reduce the ground relative velocity and increase the number of overlapped singles frames.
- Enhanced Swath, multiplying the acquired swath in a single acquisition window.

All of these modes, graphically shown in Figure 3-1, were proved in orbit via the missions that SATLANTIS has launched and is operating.

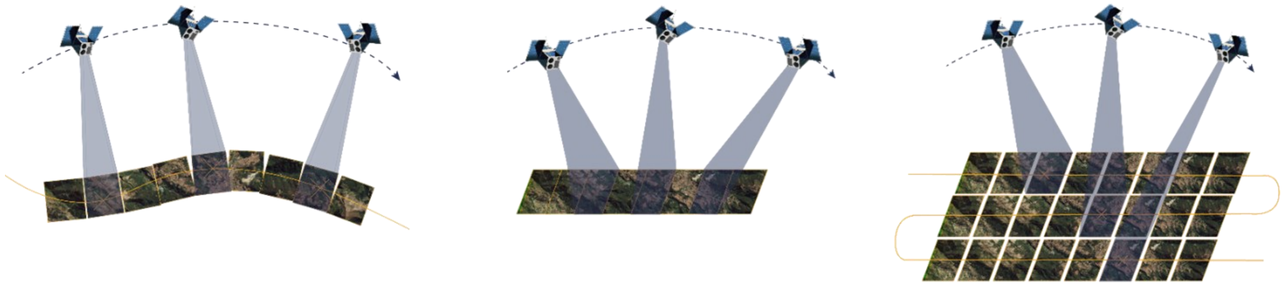

Figure 3-1: Ultra High Resolution compatible agile acquisition modes: (left) Non Linear Tracking, (middle) Back-Scanning, and (right) Enhanced Swath.

3.2 Smart Image Box

The Full Solution paradigm is additionally related to the Smart Image Box concept, also built upon the iSIM technology, that combines different technologies with the objective of improving and facilitating the payload data management from the satellite operations perspective and enhancing the payload data quality for the generation of innovative Analysis Ready Data (ARD) products through the unique characteristics described in the previous section.
To pursue such objectives, the Smart Image Box includes an Operations Toolkit and Data Processing Pipelines. The Operations Toolkit aims to increase the efficiency of the data management while facilitating satellite and data operation activities thus improving key performance indicators of an Earth Observation mission such as data delivery times or data generation capacity. The pipeline includes processing chains aimed for the generation of different Earth Observation Value Added Products, like the Methane Analytics Module developed for the GEISAT constellation [8] or other Products generated by SATLANTIS' partners in the downstream sector.

4 iSIM FOR VALUE ADDED PRODUCTS (VAPs)

As per other segments of its EO missions, SATLANTIS relies on strategic partners to leverage the push-frames technology and the other key characteristics of iSIM for the generation of Value Added Products (VAPs). Among these, two can be presented as innovation from the push-frames capability, i.e., Stereo and Video imaging.

4.1 Stereo imaging

Stereoscopic imagery is generated through the acquisition of at least two images over the same target from two different perspectives. Usually, images are taken few seconds or minutes apart in a so-called in-track stereo. State-of-the-art assets like WorldView-1-2-3 [9] and Pléiades [10] are offering stereo pairs and tri-stereo imagery but access to data can be difficult and cost-prohibitive. In addition, the multi-angle information is often difficult to obtain given the need for agile satellite platforms.

The iSIM cameras, thanks to their push-frames technology, are able to allow a wide range of manoeuvrability and agile operating modes, as presented above. Among them, it is the so-called Back-Scanning that, without the need for specific stereo acquisition, naturally creates stereo images that can be used to generate Digital Elevation Models (DEMs). This is obtained because such mode reduces the ground relative velocity and increase the number of overlapped singles frames. A simulation of such mode is presented in Figure 4-1.

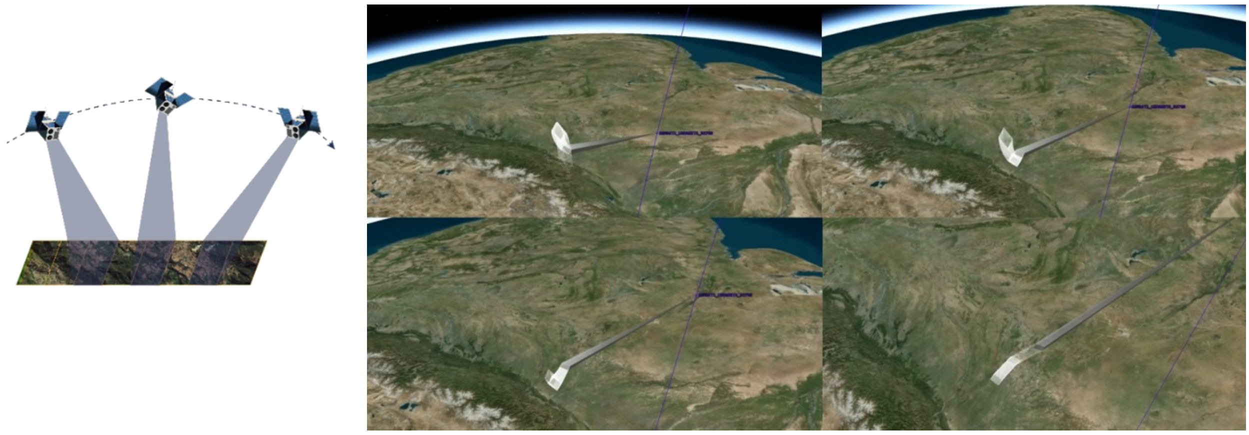

Figure 4-1: (left) Graphical representation of Back-Scanning mode and (right) simulation of a Back-Scanning acquisition over a target.

4.2 Video imaging

The possibility of generating videos from space-based assets enables a full range of critical applications, in civil (e.g., urban planning [11]) and especially for defence and security use cases, as it allows for the extraction of key information such as velocity and direction of moving objects.

Videos are generated by acquiring strips, i.e., sequences of images, combined together to create a continuous view of an Area of Interest (AoI). This capability has also been proved in orbit by SATLANTIS via its missions, as shown in Figure 4-2.

The iSIM cameras, thanks to their push-frames technology, work in a manner allowing for the acquisition of multiple images at a very high framerate (20 to 60 FPS, depending on bit depth), that can be combined to produce short videos in PAN.

On an agile satellite platform, equipped with a forward motion compensation system (i.e., allowing prolonged point and stare at a particular location, in Back-Scanning mode), the iSIM cameras can generate videos of several seconds, up to 1 minute.

Thanks to the combination between Video and the UHR algorithm, the iSIM cameras can support the video generation with two options: (a) a high video framerate (20-60 FPS) with native resolution, (b) a lower video framerate (e.g., 2-6 FPS) with enhanced resolution and higher SNR.

The objective of SATLANTIS is to deliver this product in few hours from the acquisition.

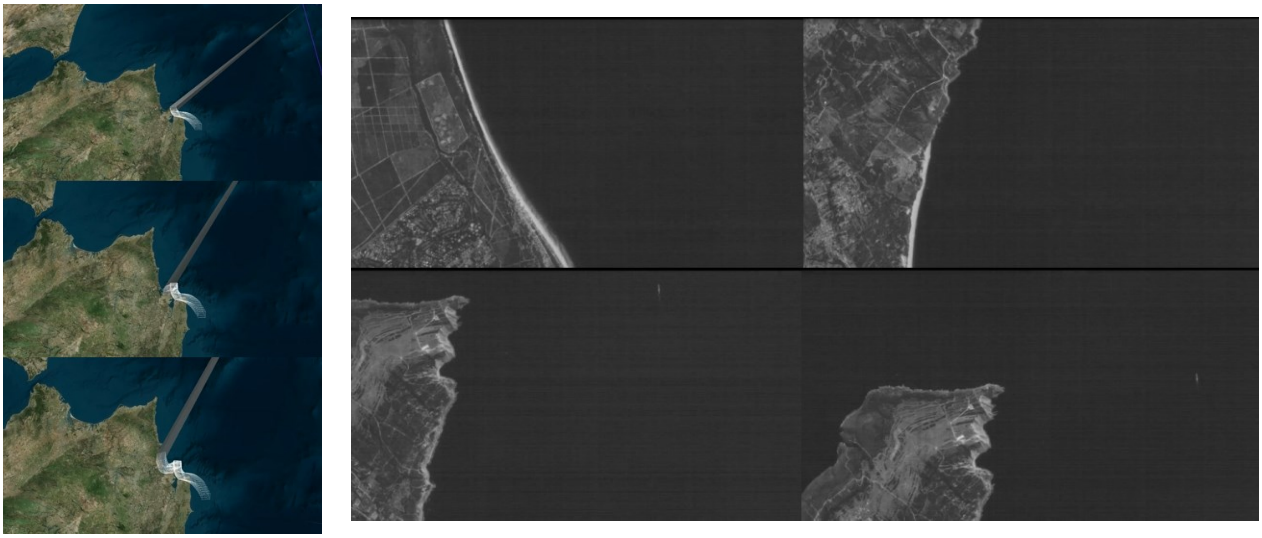

Figure 4-2: (left) Simulation of an agile acquisition for coastal monitoring and (right) few frames of the video generated over the coastline during a real acquisition.

5 CONCLUSIONS

The in-flight experience gained by SATLANTIS, together with the company effort in leveraging its iSIM technology, is proof of the contribution and added value brought by NewSpace assets to users worldwide in terms of innovation and increased capabilities. The push-frame technology specifically has been proving extremely valuable in supporting the generation of ARD products related to agile observations, multispectrality without loss of resolution, and video. The example of stereo imaging is to be further explored but preliminary results seem promising.

SATLANTIS has been active also in taking advantage of these features to impact the end-to-end mission data management and the way users are operating the space-based assets, generating and handling data, and exploiting it for various applications. The Full Solution paradigm can be considered an effort in looking for new models and optimisation of traditional processes, that are better suited for new (and NewSpace) missions, and that might pave the way for innovation all over the sector, for the benefit of final users.

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